Factors Influencing the Likelihood of Initiation of Internal Erosion Into or Along a Conduit				Date: July 2012
Factor	**Influence on Likelihood / Relative to Reclamation Historical Base Rates (see notes)**			**Comments**
	Less Likely	**Neutral**	**More Likely**	
Voids below or adjacent to the conduit	Exploration programs (GPR, coring, etc.) confirm no voids present; no reason to believe voids might exist.	No exploration information. No reason to believe voids exist.	Exploration programs (GPR, coring, etc.) have confirmed the presence of voids under or adjacent to the conduit. Much more likely if voids are believed to be extensive and continuous. Judgment is required.	Conduit exploration programs are not typically conducted unless there are signs of adverse performance or potentially high risks have been identified.
Piezometric levels along the conduit	Piezometric levels along the conduit are measured or are estimated with confidence. Piezometric levels are within expected ranges for a well-performing structure with no local high gradients.	Piezometric levels along the conduit are unknown. No reason to believe that unusual piezometric levels exist.	Piezometric levels along the conduit are measured or are estimated with confidence. Piezometric levels indicate significant variations or unusual behavior (surging, episodic responses, response to conduit flows, etc.). Much more likely if piezometric levels indicate tailwater pressure near the upstream end of the conduit, indicating a very high local gradient and a continuous upstream to downstream defect.	Piezometric information along conduits is typically not available unless are signs of adverse performance or potentially high risks have been identified.
Seepage along conduit Presence of seepage Seepage fluctuations	 No seepage Long-term steady rate of seepage unrelated to reservoir level or conduit flows	 Insignificant seepage; or seepage possible but unseen Seepage fluctuates with reservoir, but at a predictable rate	 Seepage significant Seepage is increasing over time at the same reservoir level; or seepage is episodic or surging. Seepage can be correlated to conduit flows.	Lack of seepage being observed near the downstream end of the conduit would indicate a low probability for a concentrated leak along the conduit. Determination of the presence or absence of seepage may not be known with certainty. Episodic seepage could be an indicator that an internal erosion pathway is repeatedly opening and closing. Evidence of material transport in seepage flow would indicate near certainty that erosion is occurring.
Conduit foundation	Concrete conduit constructed on a rock foundation with little or no foundation preparation. Much less likely for a concrete conduit placed on a well-prepared rock foundation.	Conduit founded on well-graded compacted soil foundation or well-graded compacted fill.	Conduit founded on loose or poorly compacted soils. Much more likely if conduit founded on fine-grained, non-plastic erodible or dispersive materials.	Settlement of foundations can result in cracking of the conduit, which can lead to internal erosion into or along the conduit. Differential settlement between the conduit and other parts of the embankment can result in cracking and/or hydraulic fracturing.

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	Less Likely	**Neutral**	**More Likely**	
Cutoff collars / seepage collars (construction techniques and compaction are closely related to this factor).	No collars used.		Collars used with wide spacing Much more likely for closely spaced collars	Originally it was thought that providing seepage collars would force a longer seepage path and reduce the potential for concentrated leaks and internal erosion. However, it is difficult to achieve good compaction around collars and experience has shown that collars may not serve their intended design intent (FEMA 2005).
Conduit geometry / trench details	Conduit constructed in a trench in rock, backfilled with concrete.	Conduit constructed in a wide trench (in non-erodible soil or rock), at least 3 feet wider than the conduit on both sides, with side slopes at 1:1 or flatter.	Conduit constructed in a narrow trench in rock, with steep excavation slopes and backfilled with soil. Conduit constructed in a narrow trench in a soil foundation with steep excavation slopes and backfilled with concrete. Much more likely for conduit constructed in a narrow trench in rock with vertical sides and backfilled with soil.	Conduits constructed in narrow trenches can result in arching of stresses between stiffer elements (e.g. bedrock trench wall and the conduit) resulting in low minor principal stresses (possibly lower than hydrostatic pressures) and hydraulic fracturing.
Sinkholes or depressions on the embankment over the conduit alignment	No observations of sinkholes or depressions, including on upstream slope areas that are normally submerged.	Minor depressions on the upstream or downstream slopes that developed slowly and do not change over time.	Observations of sinkholes or depressions on the crest, upstream slope, or downstream slope that appear suddenly.	Sinkholes or depressions that form directly over a conduit are very likely related to the conduit and are a serious concern. Exploration and evaluation are needed to evaluate each site specific situation.
Conduit joints or cracks	High quality joints; water stops; no openings	High quality joints with some open up to 5 mm, but with water stops Very small cracks visible but not open, with no leakage.	Open joints or cracks. Much more likely for open joints or cracks with signs of erosion.	Width of joints or cracks should be compared to filter criteria (no erosion, excessive erosion, continuing erosion). This factor is related to both initiation and continuation because in some cases, a crack is the cause of initiation of erosion.
Conduit structure exterior sidewall slope	Exterior constructed with a batter of 10V:1H or flatter.		Exterior constructed vertically. Much more likely if conduit constructed with overhangs.	If the conduit exterior sidewalls are constructed vertically, it may be difficult to compact against the structure to achieve a good contact between the embankment and the structure. Loose (or less dense) soils adjacent to the structure may be subject to low stresses, arching and hydraulic fracturing.

Factors Influencing the Likelihood of Initiation of Internal Erosion Into or Along a Conduit				**Date: July 2012**
Factor	**Influence on Likelihood / Relative to Reclamation Historical Base Rates (see notes)**			**Comments**
	Less Likely	**Neutral**	**More Likely**	
Hydraulic operation and control	Upstream control of water into a pressurized pipe within a concrete conduit. Inspections performed annually.	Upstream control of water into a non-pressurized conduit adjacent to the embankment. Intermediate control of water with an interior gate chamber, pressurized conduit upstream of gate chamber adjacent to embankment, non-pressurized conduit downstream of gate chamber.	Downstream control of water, pressurized conduit adjacent to embankment; high velocity flows.	Whenever a pressurized conduit is adjacent to embankment soils, the possibility exists that a defect in the conduit could expose the embankment soil to reservoir pressures. Reclamation does not have pressurized conduits in the downstream half of the embankment.
First filling	Slow first filling has been accomplished; conduit is exposed to normal maximum reservoir elevation almost annually.		First filling not yet accomplished. Conduit has never been exposed to reservoir elevation near the normal maximum. Much more likely if a rapid first filling is likely (and cannot be avoided).	A rapid first filling may not allow slow wetting of earthfill; may not allow re-distribution of stresses. Cracks and hydraulic fractures could form if a rapid filling does not allow soils to adjust and compress against the conduit.
Settlement	Conduit founded on dense materials, little or no settlement,	Some settlement but conduit has good design details	Large settlement, no design details to accommodate.	Survey inside conduits is not always possible; signs of settlement include concrete cracking and ponding of water on the conduit floor.
Connection to other structures	No other structures in the impervious zone	Good connection details between conduit and other structures within the impervious zone (e.g. central shaft or interior chamber).	Poor connection details between conduit and other structures within the impervious zone (e.g. central shaft or interior chamber).	Poor connection details between the horizontal conduit and other structures could lead to localized settlement, cracking or low stress zones.
Conduit exterior finish	Smooth (steel or formed concrete)	Rough	Corrugated exterior	Good contact between the structure and the embankment fill is difficult to achieve if there are corrugations, or similar irregularities.
Conduit type	Concrete-encased steel conduit Concrete case in situ	Concrete-encased cast iron Concrete precast	Steel or cast iron, not encased. Much more likely for round conduits (not encased), masonry, brick, corrugated steel.	This factor is low on this table because most Reclamation conduits are concrete. However, for non-Reclamation dams, this would be a significant factor to consider.
Conduit corrosion	Concrete conduit; non-corrodible conduit; new steel with corrosion protection	Cast iron (< 20 years); steel (< 10 years); corrugated metal (< 5 years).	Old cast iron (> 60 years); old steel (> 30 years); old corrugated metal (> 10 years). Much more likely for old corroded cast iron or corroded steel.	This factor is low on this table because most Reclamation conduits are concrete. However, for non-Reclamation dams, this would be a significant factor to consider.

Notes on use of Table:

1. The factors on this table are specifically for potential failure modes related to internal erosion into or along a conduit. Similar factors would apply to any potential failure mode involving an upstream to downstream penetration (e.g. spillway wall, instrumentation trench, etc.). Many other factors listed in the "Initiation of Internal Erosion through the Embankment" table are also relevant (e.g. erodibility, compaction of fill, construction factors, etc.) and should be considered when evaluating initiation of internal erosion into or along a conduit.

2. Table is intended to provide guidance in addition to historical base rates of initiation of internal erosion. The neutral factors listed in the table would correspond to average base rates. Neutral factors do not imply a 50% probability. In general for a given Reclamation dam, there would be justification to select a probability of initiation of internal erosion higher than historical base rates if that dam was characterized by multiple "more likely" factors listed above; and conversely, there would be justification to select a probability of initiation of internal erosion lower than historical base rates if that dam was characterized by multiple "less likely" factors. Whether the estimated probability of initiation of internal erosion is higher, lower or at the historical base rate, the justification for the estimated probability must be documented. This table provides some guidance for that justification.

3. Some factors listed on the table apply to all internal erosion mechanisms (backward erosion piping, internal migration, scour, suffusion/suffosion) while some factors might only apply to one mechanism.

4. Some factors listed on the table are more critical to initiation of internal erosion along a conduit than others. In general, more influential factors are listed towards the top of the table and less influential factors are listed towards the bottom.

5. Expert guidance is critical for interpreting observations at a dam and making judgments that relate performance of a specific dam to historical base rates of internal erosion.

References:

Technical Manual: Conduits through Embankment Dams, Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation and Repair, FEMA 484, September 2005.

Draft Risk Analysis Methodology Appendix E (2000), Estimating Risk of Internal Erosion and Material Transport Failure Modes for Embankment Dams, version 2.4, Bureau of Reclamation, Technical Service Center, Denver, CO. August 18, 2000. (This document was never finalized; it was superseded in 2008 by Dam Safety Risk Analysis Best Practices Training Manual, Chapter 24.)

Fell, R., C.F. Wan, and M. Foster (2004), "Progress Report on Methods for Estimating the Probability of Failure of Embankment Dams by Internal Erosion and Piping," University of New South Wales, Sydney, Australia. UNICIV Report 428. 2004.